650V GaN Based 3.3kW Bi-Directional DC-DC Converter for High Efficiency Battery Charger with Wide Battery Voltage Range

Feng Qi, Zhan Wang, YiFeng Wu

Transphorm Inc.

978-1-5386-8330-9/19/$31.00 ©2019 IEEE

Paper ID - 1837

Questions You May Have … …

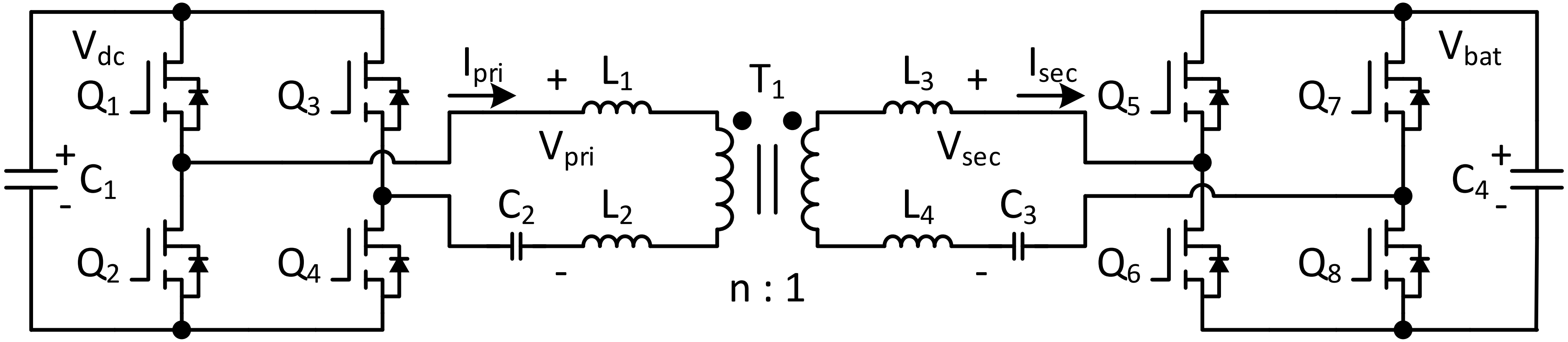
- Why should I use GaN for battery chargers?
- What can I get from a classic topology with GaN?
- How much more can I achieve with GaN?

Questions You May Have … …

- **Why should I use GaN for battery chargers?**
- What can I get from a classic topology with GaN?
- How much more can I achieve with GaN?

transphorm

Bi-Directional DC-DC Converter Overview



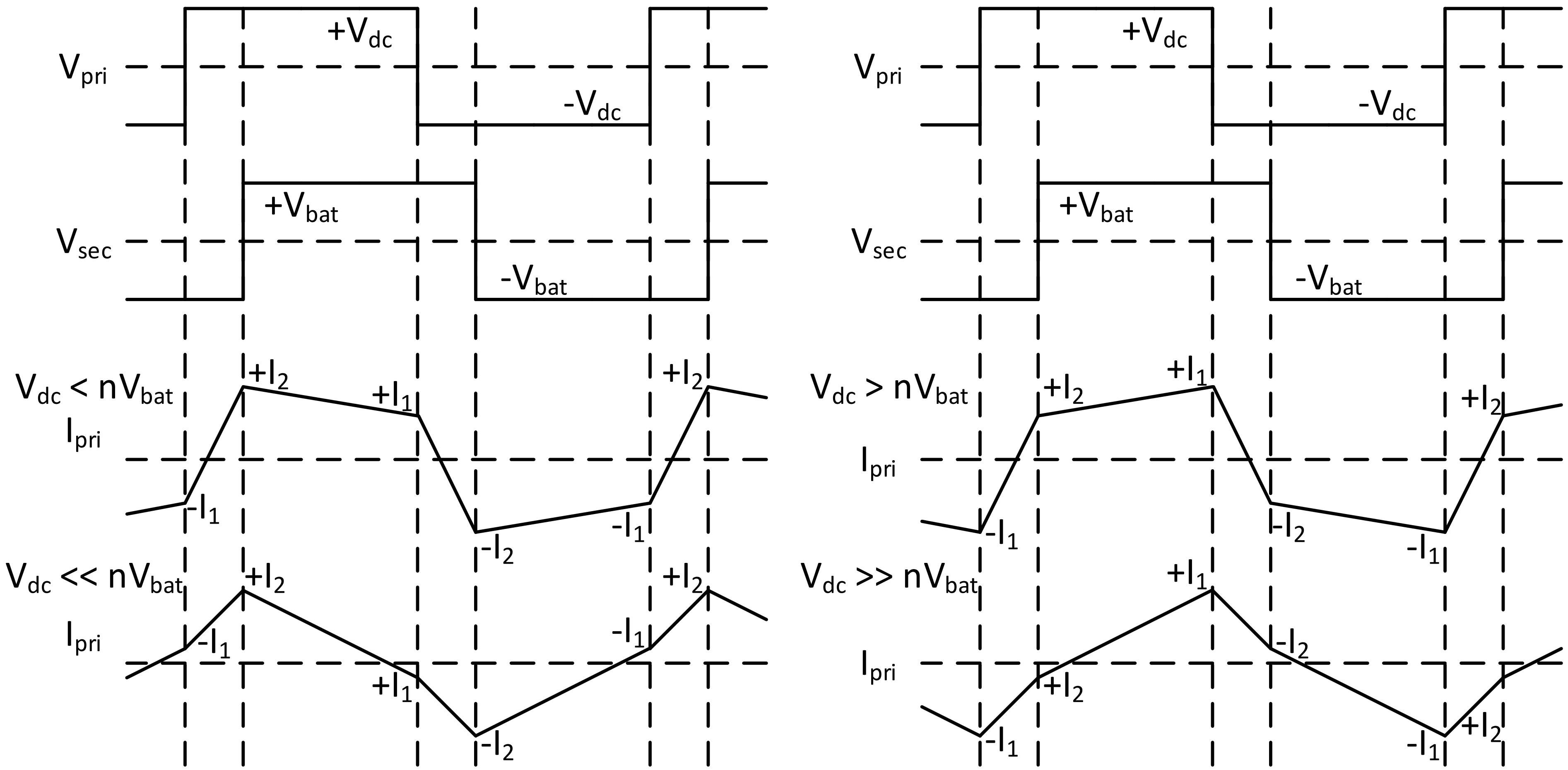
Topoloty	Dual Active Bridge
DC-link Voltage, V_{dc} (V)	380 ~ 410
Battery Voltage, V_{bat} (V)	250 ~ 450
Maximum Power (W)	3300
Maximum Current (A)	11
Q1 – Q8	TPH3205WSBQA
Switching frequency, f_{sw} (kHz)	100
Transformer turns ratio (n : 1)	1.125:1
Inductors, L1 – L4 (μH)	6.5
DC blocking capacitor (μF)	5
Max. Phase Shift Angle	0.2π

transphorm

Dual Active Bridge Review - Charging

Soft Switching

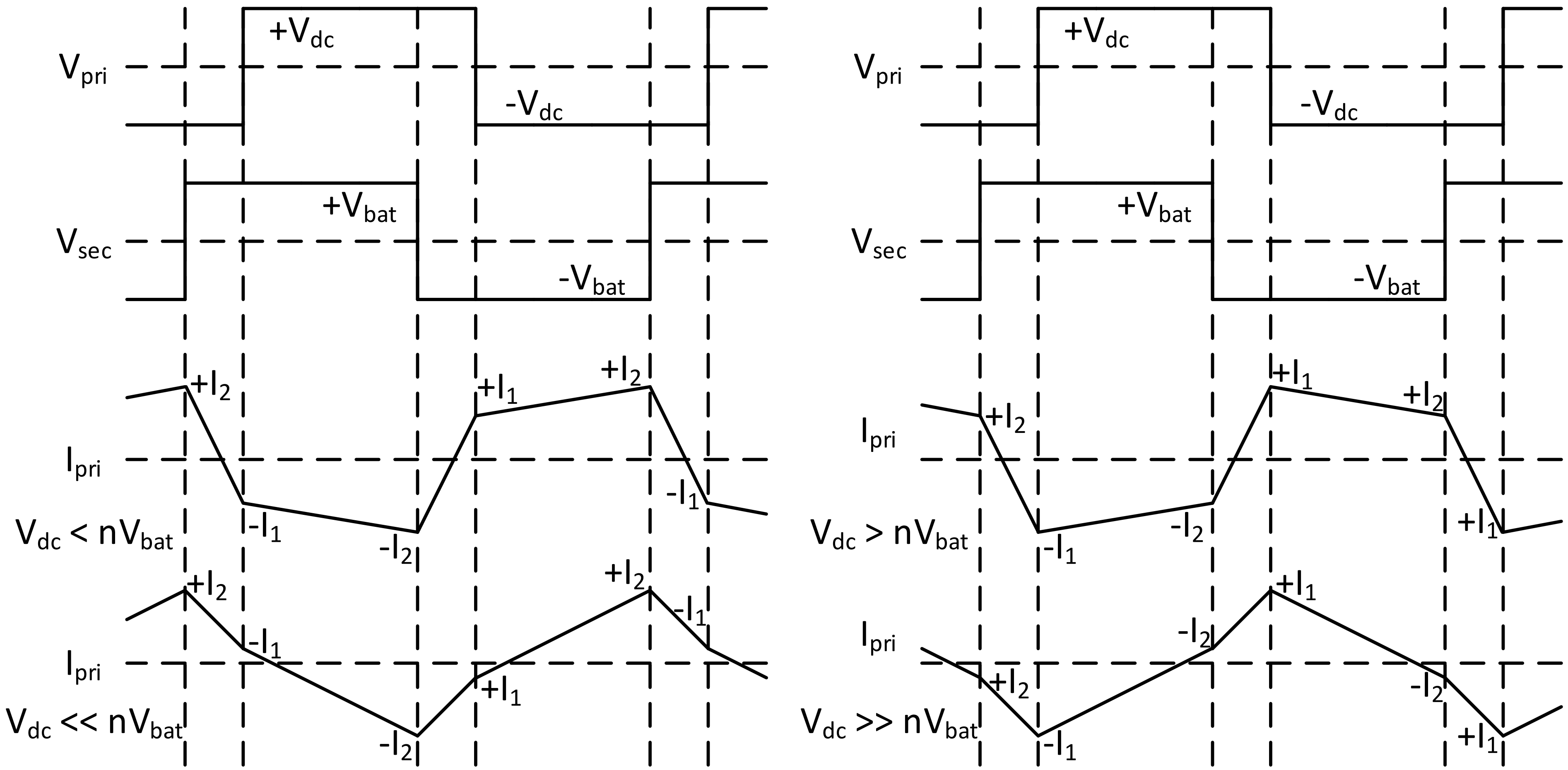
Hard Switching



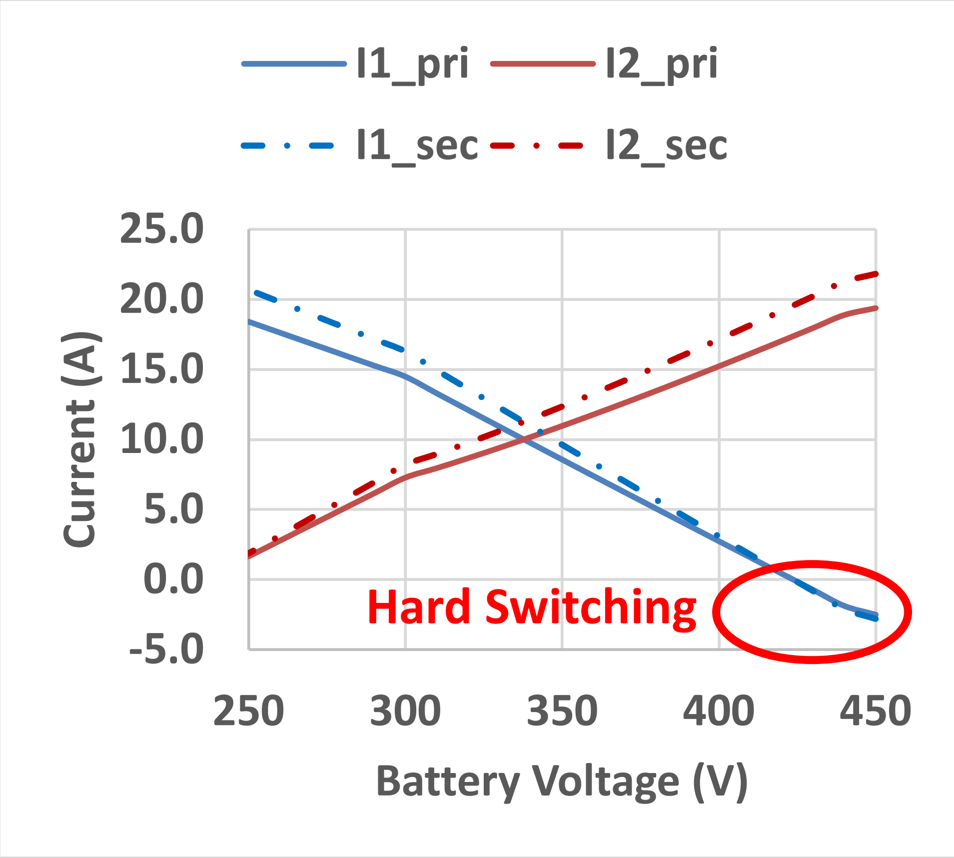
Dual Active Bridge Review - Discharging

Soft Switching

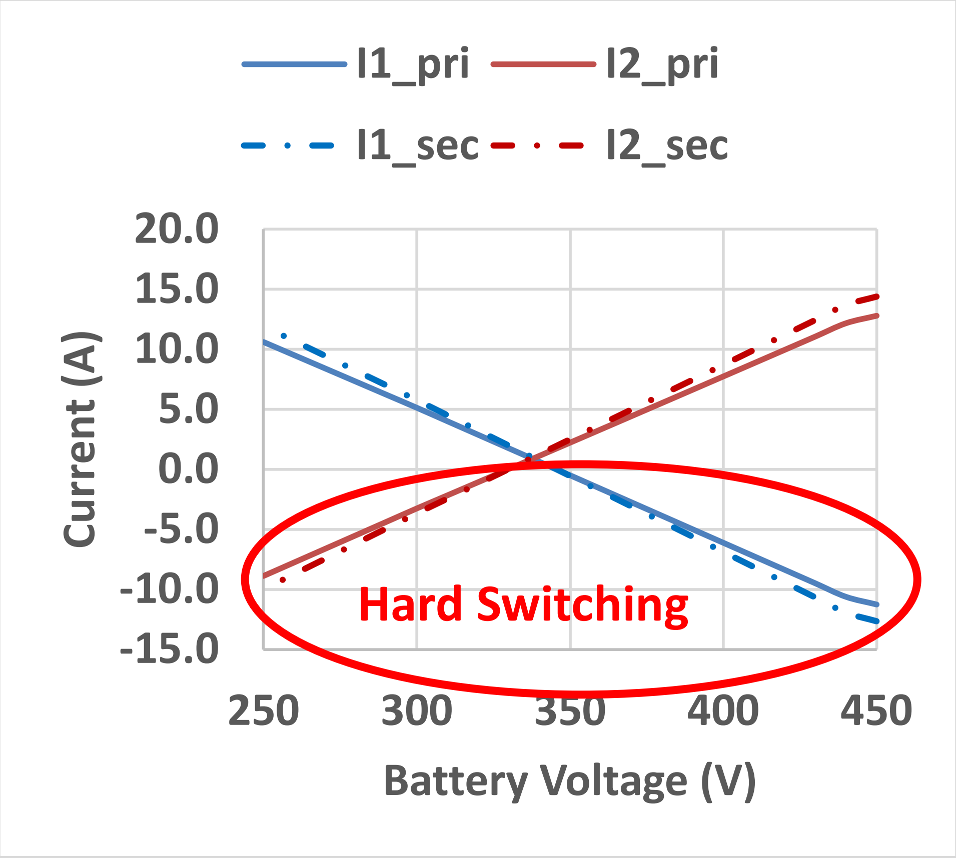
Hard Switching



Current at Voltage Alternation - I1 and I2



Full Power – 3.3kW



10% Power – 0.3kW

transphorm

Why Should I Use GaN for Dual Active Bridges?

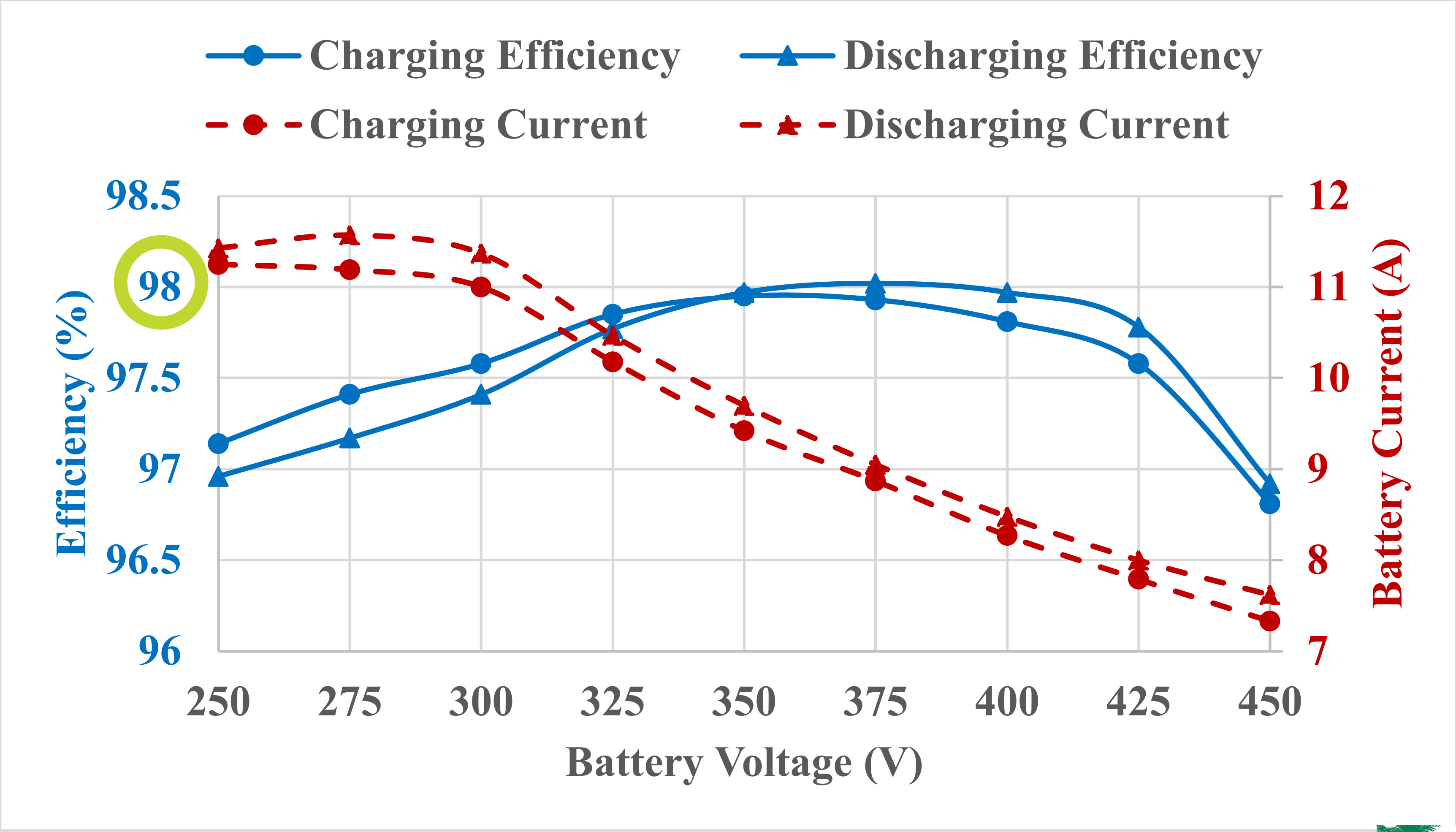
	TPH3205WSB QA	IPW60R055 CFD7	IPW60R060 C7
Vds	650 V	600 V	600 V
Ron typ	49 mΩ	46 mΩ	52 mΩ
Qoss typ	108 nC	469 nC	420 nC
Qrr typ	**136 nC** 22A, 1000A/us	**770 nC** 12A, 100A/us	**6 μC** 16A, 100A/us
switching loss of a phase leg (without VI loss)	109 μJ	616 μJ	4.8 mJ

More than 80% reduction of charge related loss!!!

Questions You May Have … …

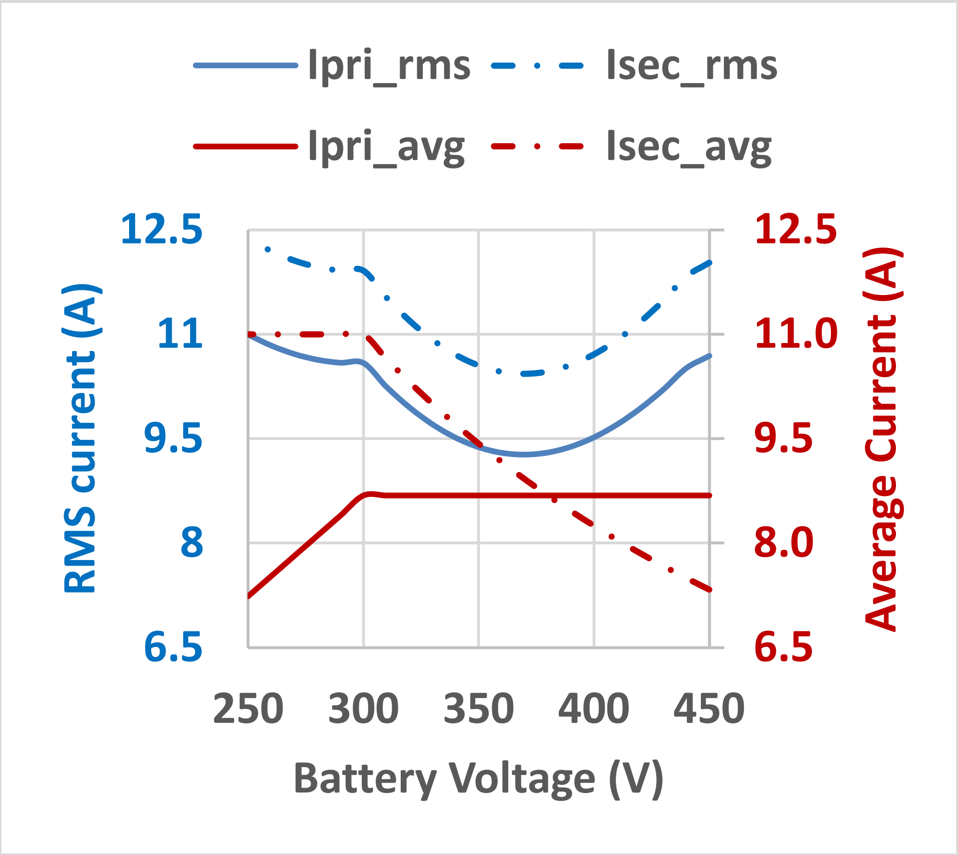
- Why should I use GaN for battery chargers?
- What can I get from a classic topology with GaN?
- How much more can I achieve with GaN?

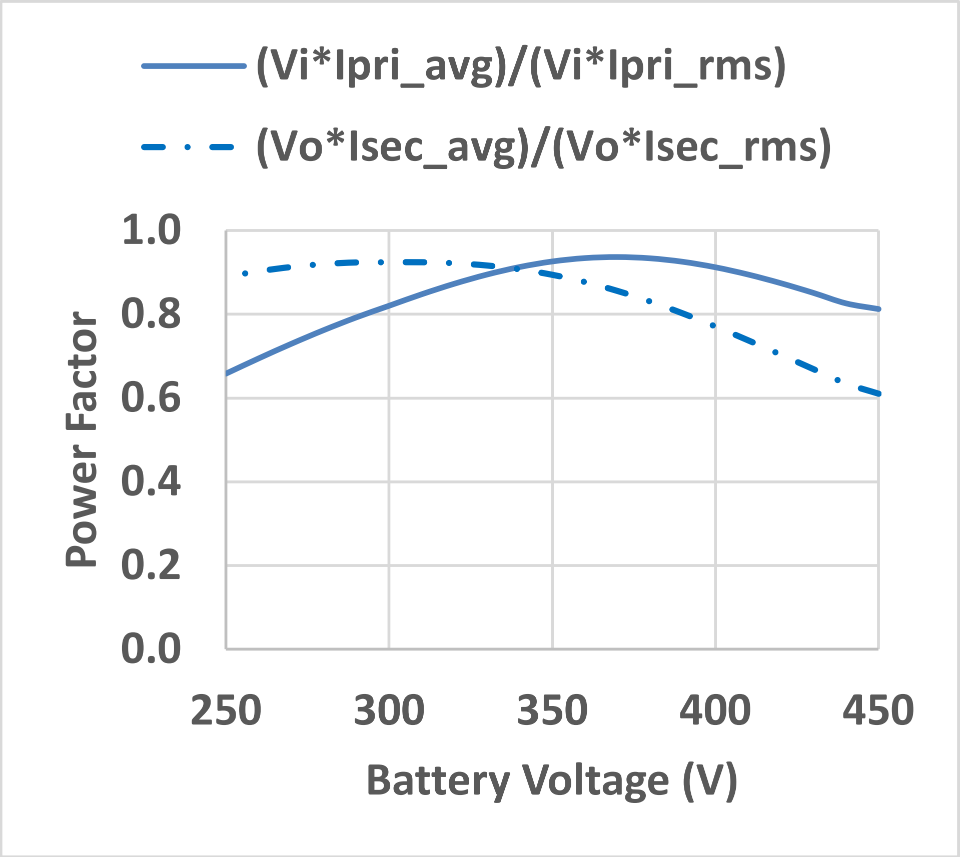
Charging and Discharging at 380VDC, 3.3kW



transphorm

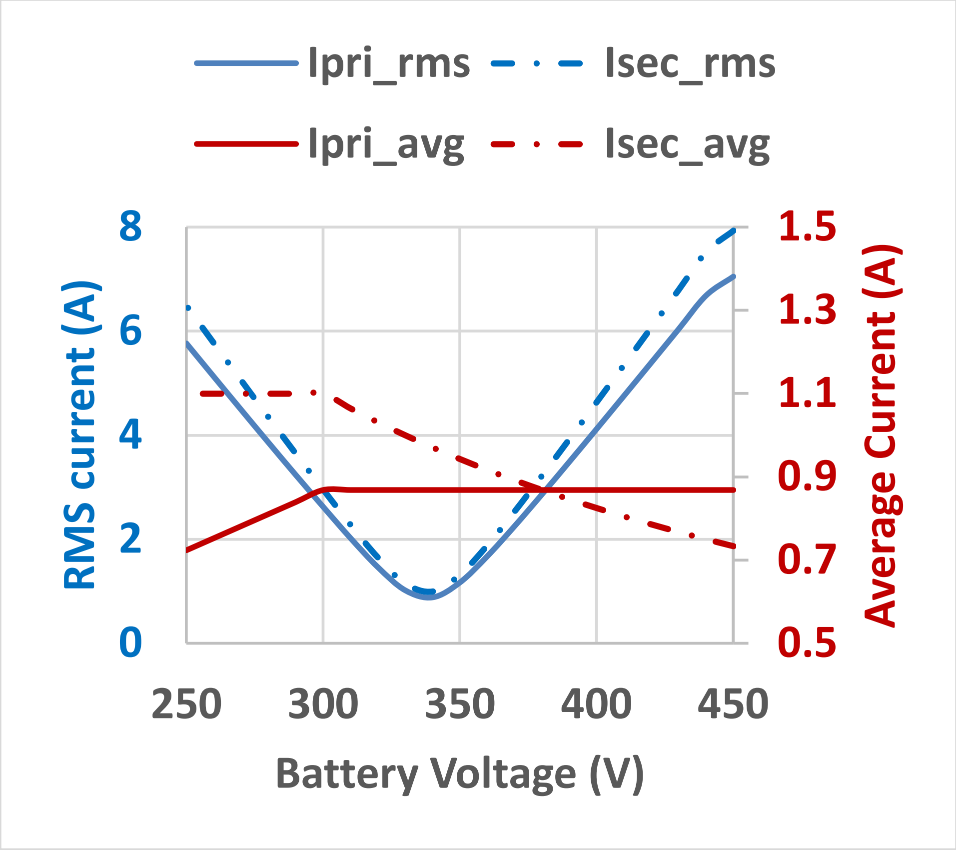
Power Factor of Full Bridges at 380VDC, 3.3kW

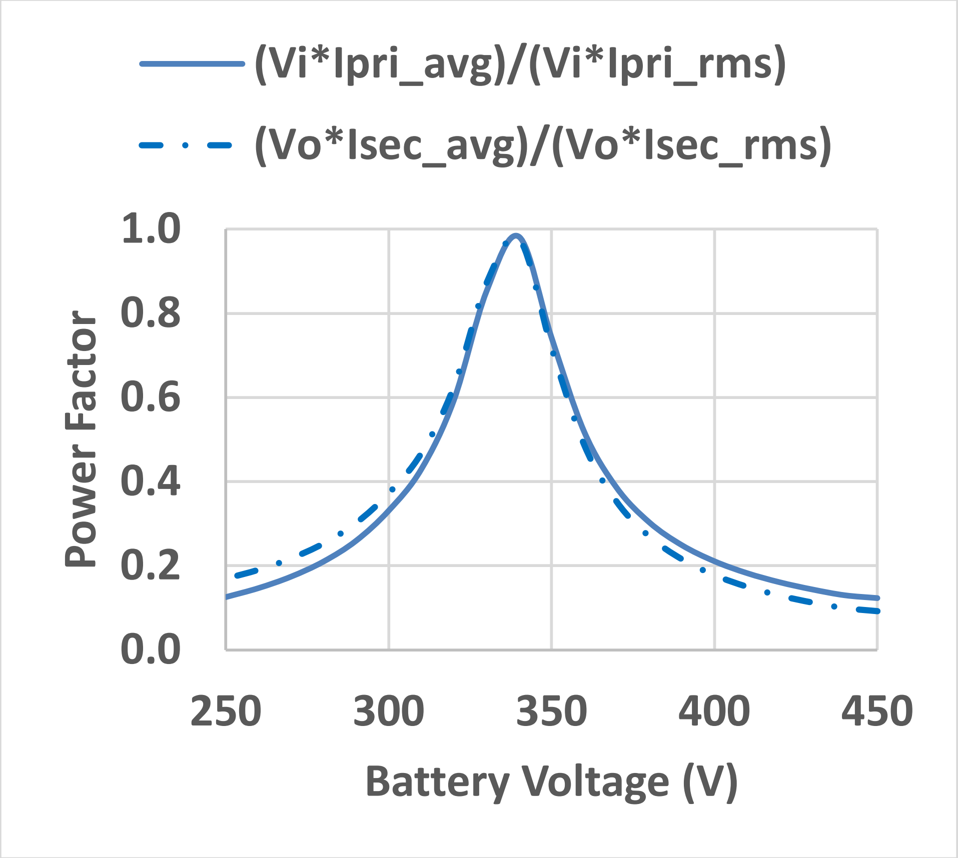




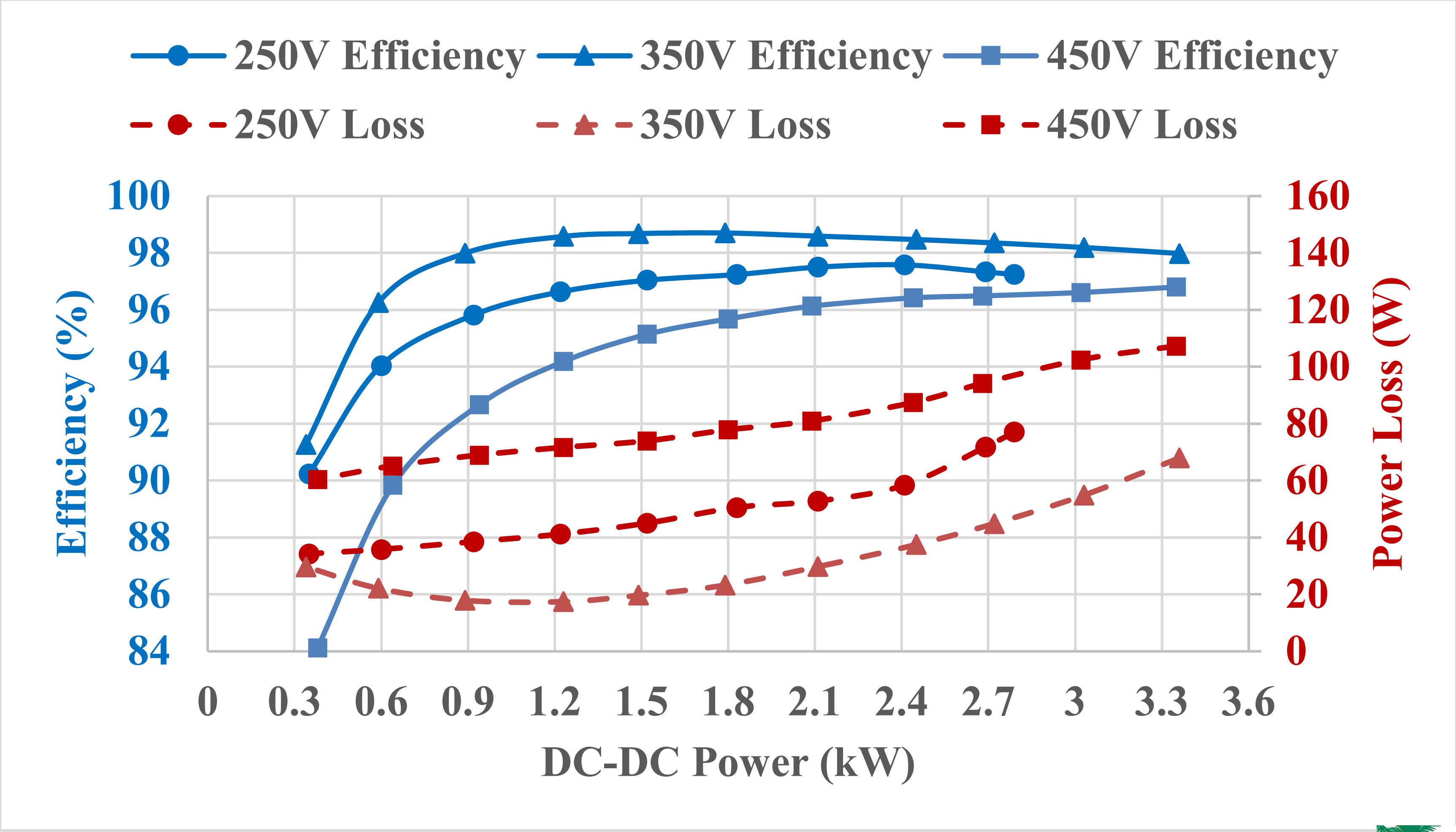
APEC 2019
MARCH 17-21 | ANAHEIM, CA.
ANAHEIM CONVENTION CENTER

Power Factor of Full Bridges at 380VDC, 0.3kW



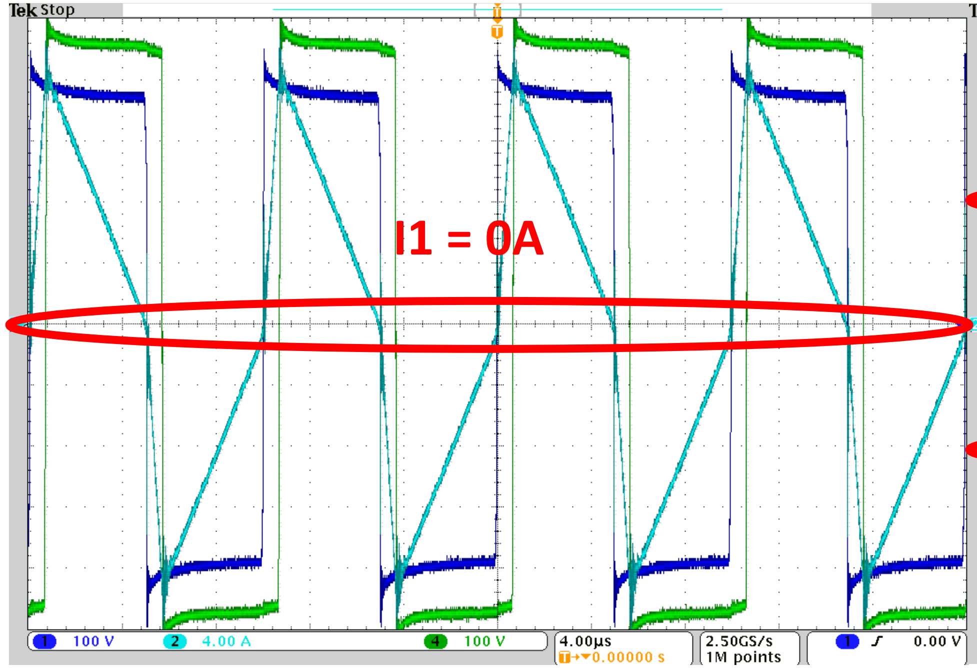


250V, 350V, and 450V Charging at 380VDC

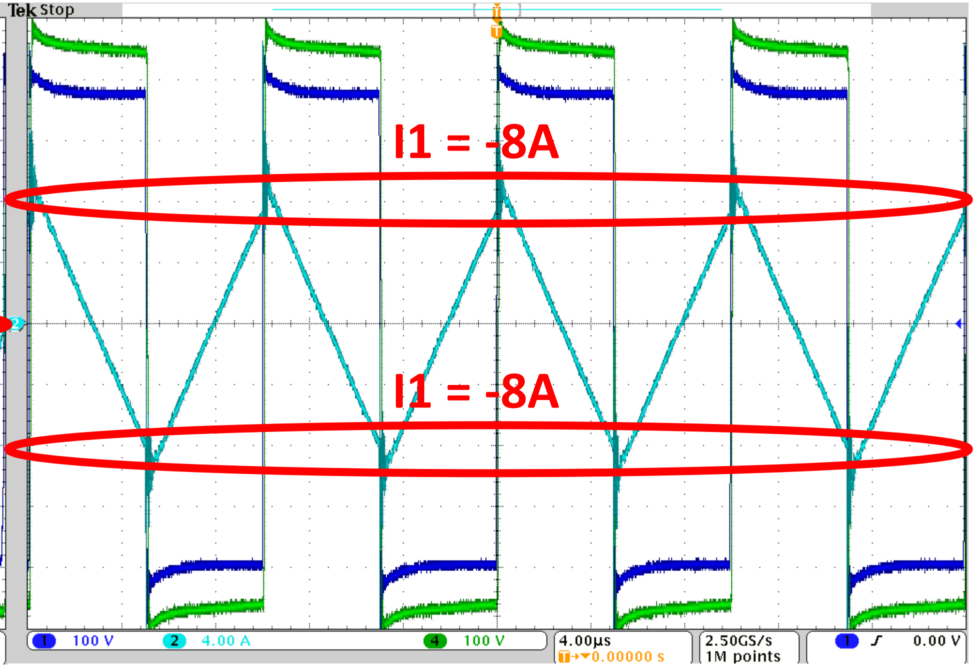


transphorm

Hard Switching at 450V Charging, 380VDC



450V charging, 380VDC, 3.3kW

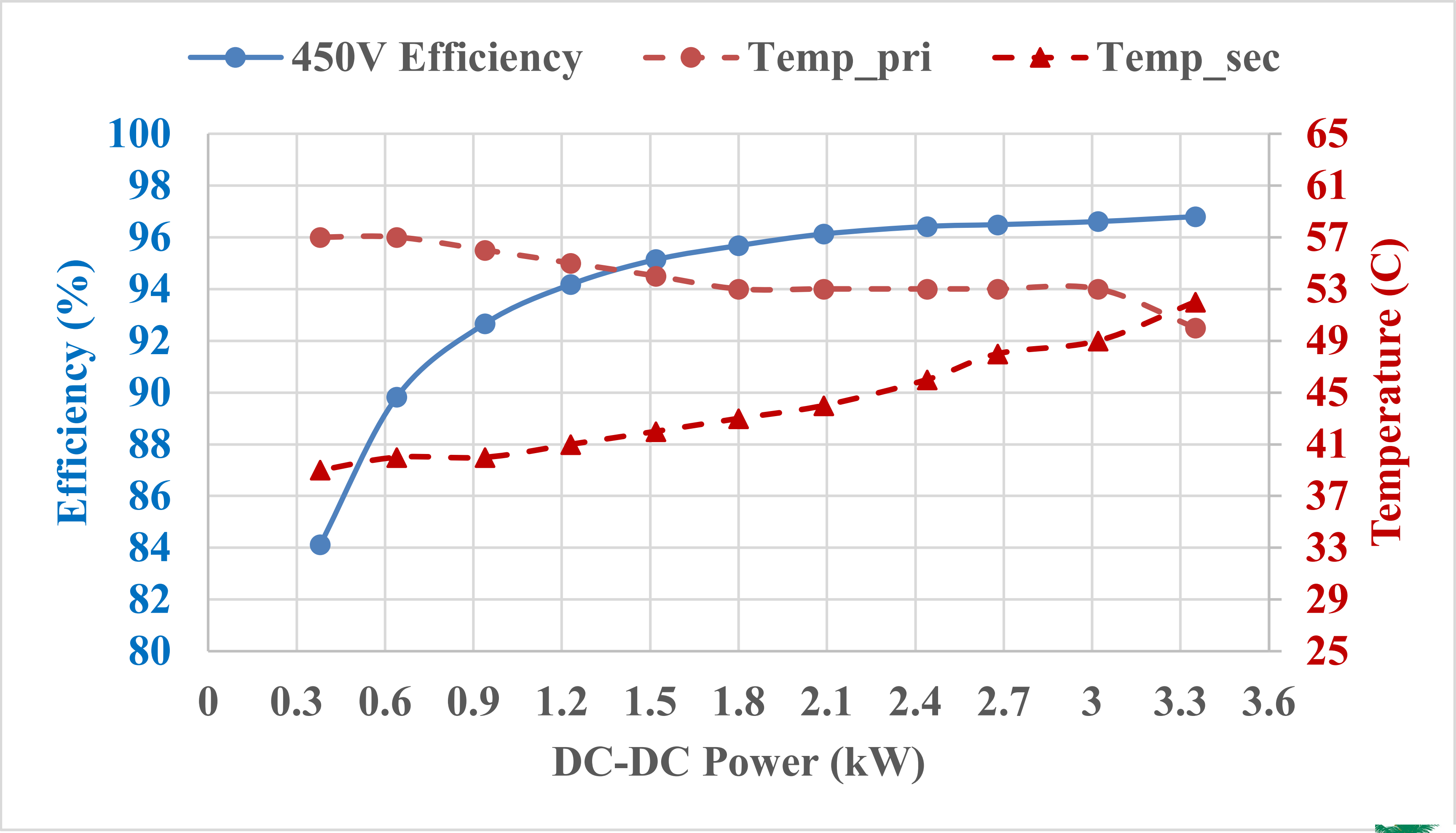


450V charging, 380VDC, 0.3kW

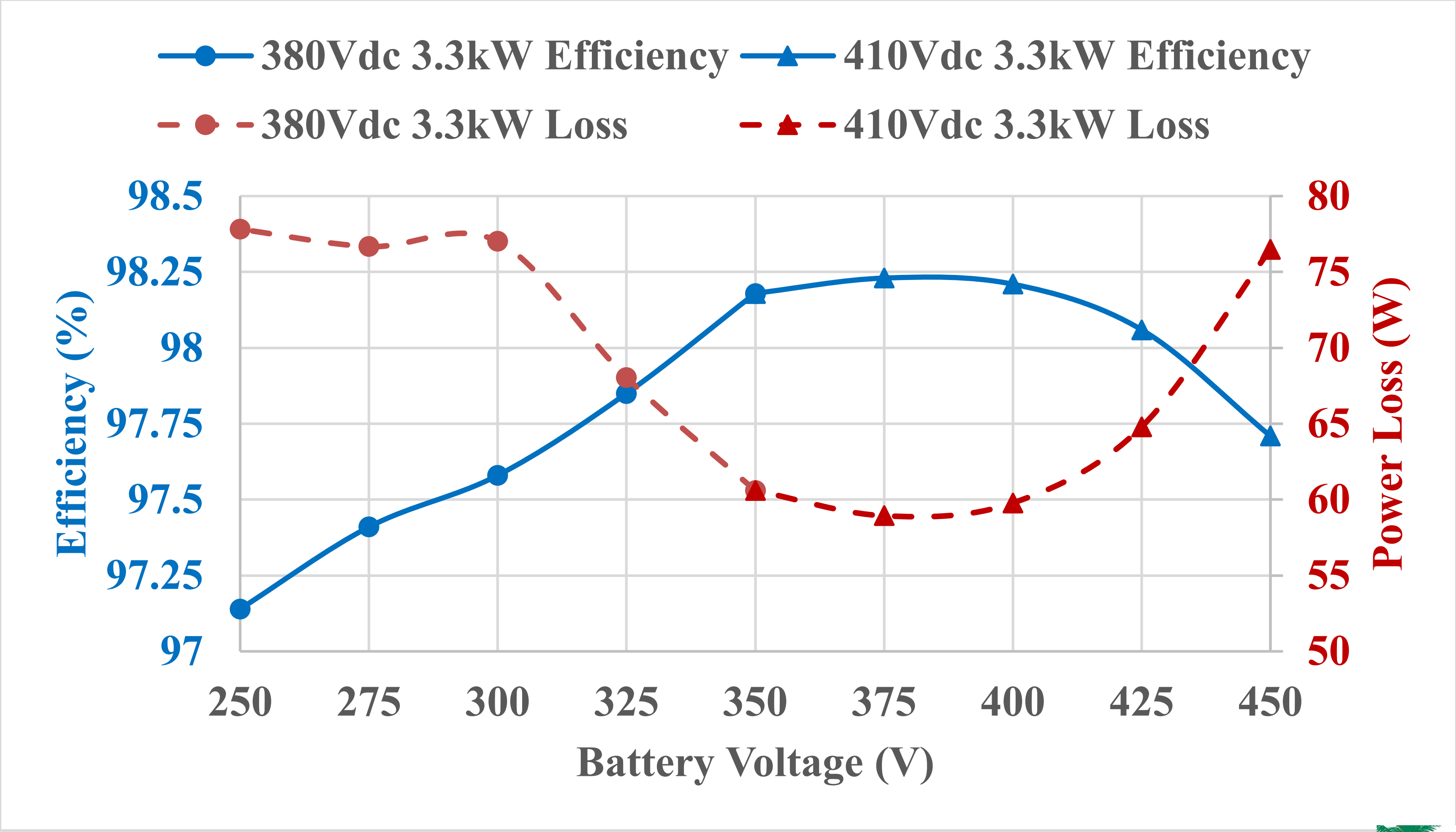
Primary side devices are switched around 0A, which gives very limited energy to obtain zero voltage switching.

Primary side devices are turned on when 8A is freewheeling in the complementary device at the same phase leg.

Device Temperature at 450V Charging, 380VDC



Charging with Simple DC-link Adjustment



Questions You May Have … …

- Why should I use GaN for battery chargers?
- What can I get from a classic topology with GaN?
- **How much more can I achieve with GaN?**

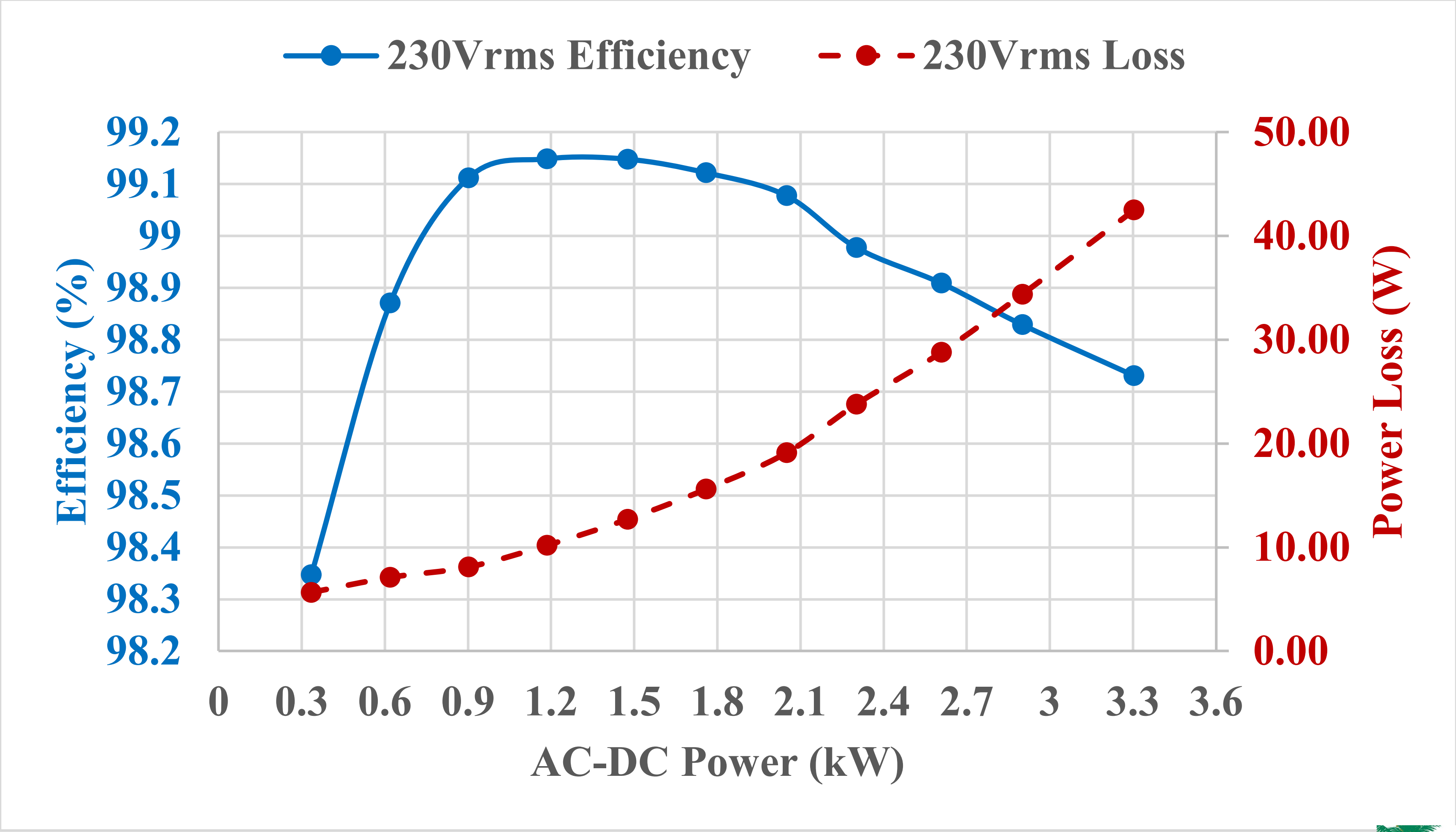
Real World Proven GaN Totem Pole AC-DC

CORSAIR AX1600i

Bel Power TET3000-12-069RA

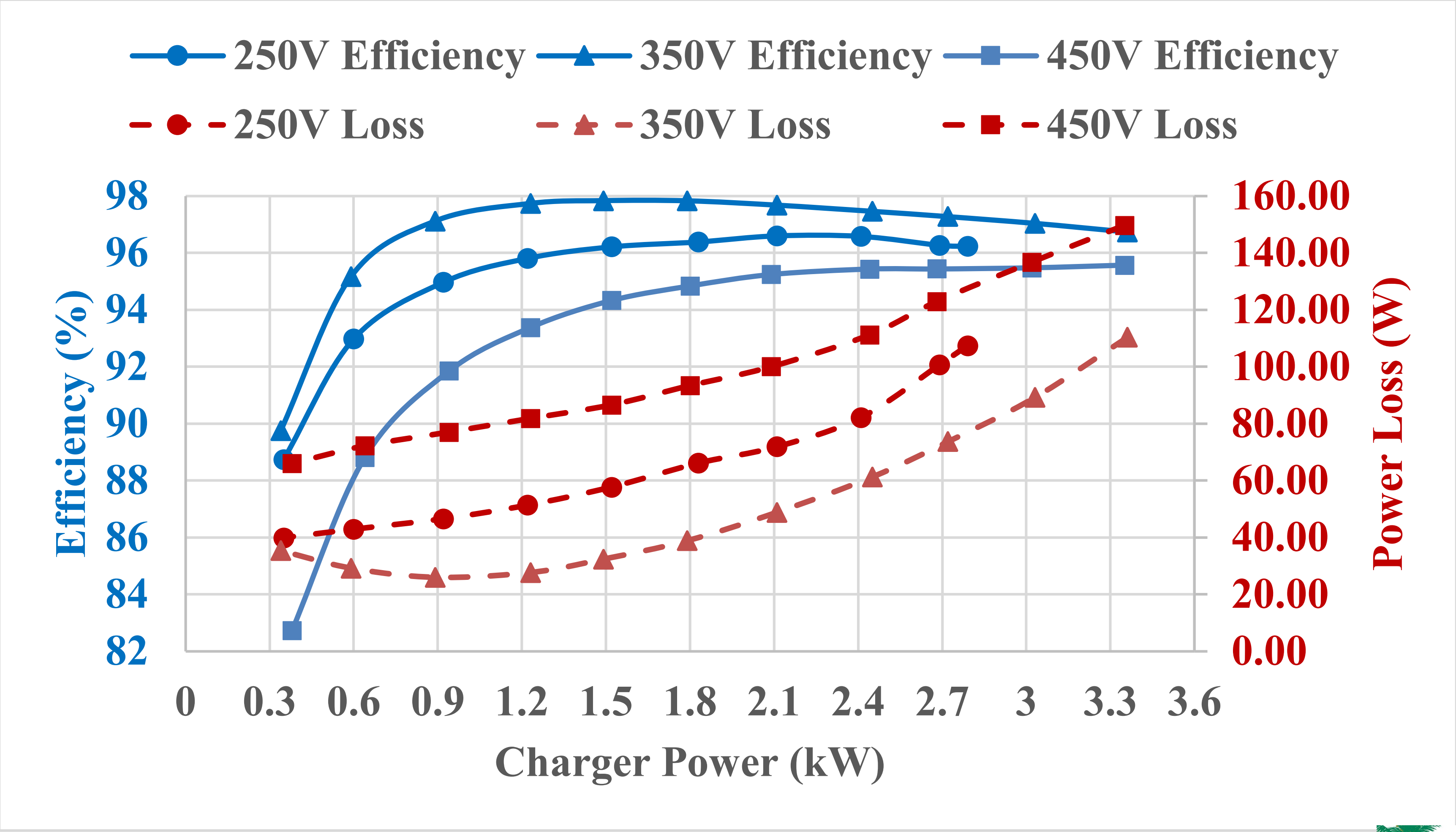
transphorm

GaN Totem Pole AC-DC at 230VAC and 380VDC



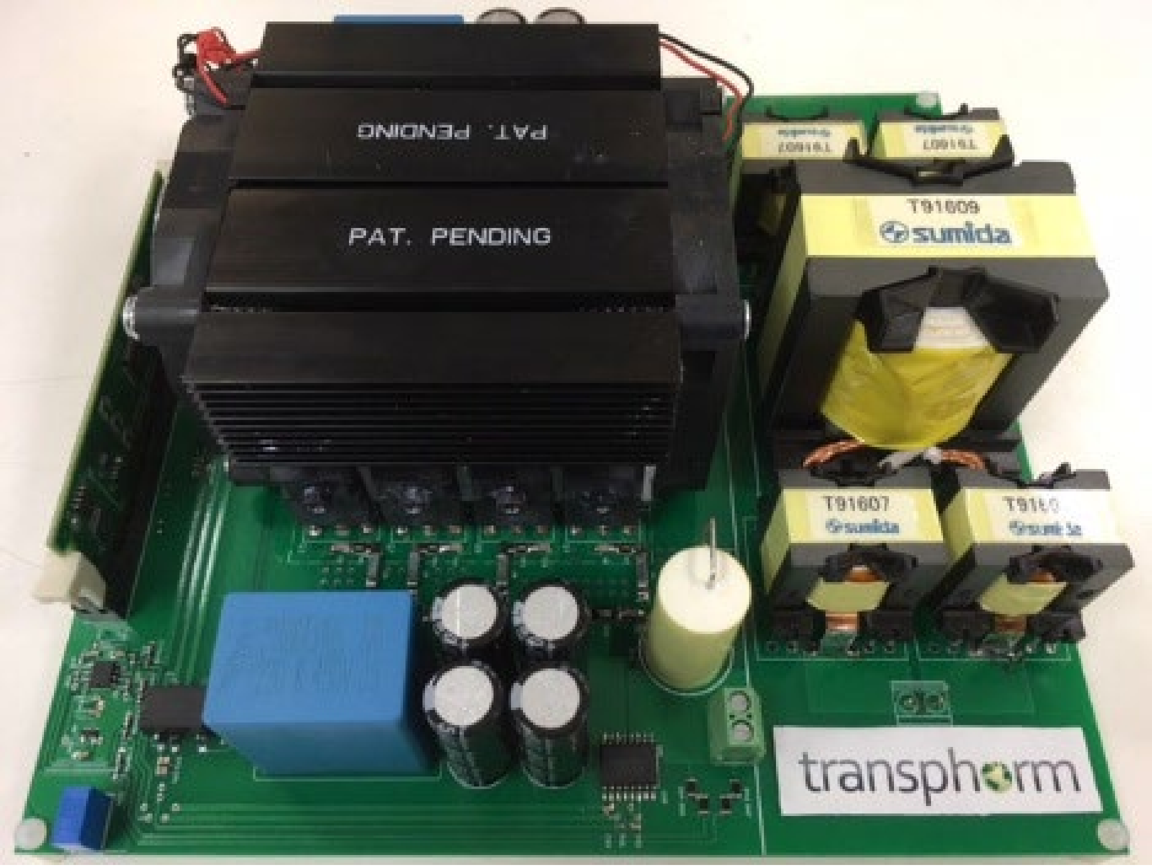
APEC 2019
MARCH 17-21 | ANAHEIM, CA.
ANAHEIM CONVENTION CENTER

Expected Charger at 230VAC and Fixed DC Link



transphorm

Bi-Directional DC-DC Converter Prototype



Transformer Core	**PQ50/50, 3C95**
Transformer Primary Winding	18 turns, 435/40AWG
Transformer Secondary Winding	16 turns, 435/40AWG
Inductor Core	PQ26/20, 3F36
Inductor Winding	6 turns, 270/40AWG
DC-blocking Capacitor	505PHC250K

APEC 2019
MARCH 17-21 | ANAHEIM, CA.
ANAHEIM CONVENTION CENTER

transphorm

Volume v.s. Frequency

	100kHz DAB	300kHz SRC [11]
Transformer Dimension (mm)	1 set of PQ50/50 L 50, W 30, H 50	Integrated PQ50/54 L 50, W 30, H 54
Inductor Dimension (mm)	4 sets of PQ26/20 L 26, W20, H 20	Integrated PQ60/60 L 50, W 30, H 54
Volume (mm^3)	116,600	81,000
Frequency (kHz)	100	300 to 600 determined by voltage and load

Do you want 50% more volume of magnetics at 100kHz or:

- **200% higher switching frequency, 300kHz, at high power?**
- **500% higher switching frequency, 600kHz, at light load?**

Do you want a classic topology or:

- **Novel topologies with variable frequency?**
- **Novel topologies with variable DC-link?**

transphorm

Takeaway

- Why should I use GaN for battery chargers?
  - **Low switching loss caused by Qoss and Qrr**
- What can I get from a classic topology with GaN?
  - **High efficiency at fixed DC-link, and higher efficiency with simple DC-link adjustment**
- How much more can I achieve with GaN chargers?
  - **With real world proven GaN Totem Pole AC-DC, maximum power loss of a 3.3kW charger is expected to be within 150W in total.**
  - **High power density at fixed switching frequency and fixed DC-link voltage.**
- **More discussion on production use of GaN at IS16**